Maintaining the Balance

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The correct functioning of our bodies hinges upon precise energy management: neither excessive energy expenditure nor inordinate conservation will keep us in good shape

All forms of activity in the human body require a supply of energy: synthesizing chemical compounds, transporting substances through cell membranes, sustaining blood circulation, maintaining our internal body temperature on a stable level, and using muscles to perform work. The body receives energy in the form of the high-energy chemical compounds, such as fats, carbohydrates and proteins, contained in food. Some of the energy released through oxidation is dissipated in the form of heat, while the remainder is stored away in small portions, in the form of high-energy chemical bonds in adenosine triphosphate (ATP) molecules. This compound mediates in the transfer of energy from the systems where it is released to the systems where it is used. Nevertheless, cells only contain very small reserves of ATP, and so it needs to be constantly produced at a rate conforming to the pace of energy consumption.

The energy processing system in living organisms generally shows very high efficiency. However, the efficiency rate varies across different tissues and may change in response to conditions. When we are riding a bicycle at moderate speed, the energy efficiency of our muscles is 20-25%. Even greater efficiency is achieved while we are walking or running, thanks to the alternating contraction and extension of opposing muscle groups. Muscle extension causes potential energy to be stored in spring-like elements (the tendons),

Professor Krystyna Nazar studies the physiology of physical effort, and the consequences of physical training and inactivity

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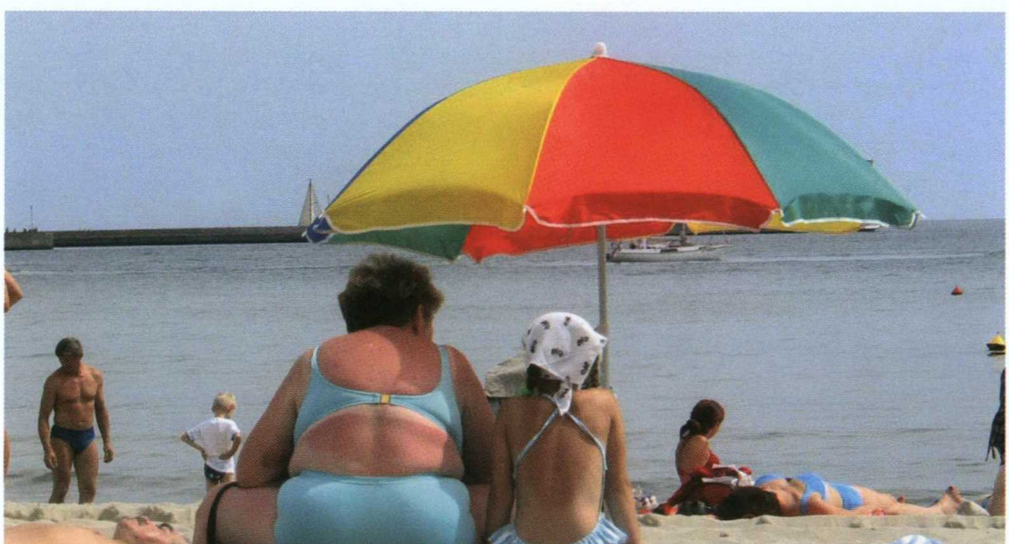

The only salvation for modern societies involves greater preventative action to combat epidemic obesity, chiefly by encouraging greater physical activity and improving bad eating habits

to be subsequently utilized during the contraction phase.

Revving up in neutral gear

Living organisms also have mechanisms that cause energy to be converted into work at a lower efficiency, owing to the presence of special protein substances that disrupt the relationship between the oxidation of high energy substances and synthesis of ATP. This mechanism makes it possible for an organism to boost its production of heat in a low-temperature environment, and is very well-developed in animals and in human infants. They have concentrations of "brown fat" tissue rich in a protein called thermogenin (the "uncoupling" protein), which lowers the energy efficiency of ATP breakdown, thereby causing increased heat production. Such tissue largely disappears in adult humans, although they do retain small concentrations and individual cells dispersed throughout the subcutaneous fat tissue.

The average daily energy expenditure of an adult human totals from 8,000 to 12,500 kJ. But this figure can even reach 25,000 kJ per day for heavily training sportsmen

Another mechanism causing energy losses consists of so-called "futile cycles." These processes consist of two irreversible chemical reactions working in opposite directions, i.e. the synthesis and breakdown of the same complex substance. The concurrent activation of both such reactions gives rise to increased heat production. Such idle cycles are stimulated by certain hormones, such as thyroid hormones and adrenaline.

Under normal conditions, the average daily energy expenditure of relatively physically active adult human totals from 8,000 to 12,500 kJ. Some 70-75% of this is consumed by resting thermogenesis, meaning the energy expenditure required to sustain life processes, a further 20% is spent on motor activity, while 10% consists of "post-meal thermogenesis," meaning the increased energy expenditure that occurs immediately after food consumption.

If the body's daily food ration supplies energy in amounts equal to its daily expenditure, there is an energy balance and body weight does not change. This does not mean, however, that this balance is equilibrated every day. An extended period of intensive effort might entail a daily energy expenditure that is several times higher than that seen on an inactive day. The short-term effect of such an energy deficit is easily compensated for, due to energy stocks laid away in the form of fat in fat cells or in the form of polysaccharide, glycogen, stored in the liver (a reserve of some 100-110 g) and in the muscles (300-400 g).

Yet certain cells, such as neurons, cannot make use of fatty acids. They require a constant supply of glucose (the brain consumes some 140 g daily), but the body's reserves of this sugar are very modest. A person after overnight fast has some 15 g of glucose in their blood and intercellular fluid. This chiefly derives from the breakdown of the glycogen in the liver, because the glycogen stored in the muscles can only be used when they are working, and is not a source of glucose released into the blood. When we are fasting and has no glucose coming in from the digestive system, it thus has to intensively generate glucose from other compounds, chiefly from amino acids, which are components of proteins.

Feed the brain!

The process of conserving glucose to meet the brain's needs is of fundamental significance not only during starvation, but also during extended strenuous effort. Under such conditions, working muscles not only consume the glycogen stored in them, but also uptake further glucose from the blood. Glucose saving is made possible by the increased availability of fatty acids. At our centre, we have researched the physiological mechanism that works to prevent a dangerous reduction in the blood's glucose concentration during physical effort (the glucostatic mechanism). This mechanism chiefly functions by boosting the activity of the sympathetic nervous system and the secretion of hormones such as adrenaline, glucagon, and cortisol - these hormones stimulate the release of glucose from the liver's glycogen and its synthesis using other substrates, and encourage the breakdown of fats in fat tissue. Also of important significance is the reduced secretion of insulin, a hormone that causes the opposite effect.

Our research has shown that the extent of the neuro-hormonal reaction to physical

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When we are riding a bicycle at moderate speed, our muscles are working with 20-25% energy efficiency

effort depends on the body's carbohydrate resources. The glucostatic mechanism is successfully set into motion before a reduction in the blood's glucose concentration actually occurs, owing to the fact that information about the metabolism of glucose in the liver, and presumably also about the processes taking place in the muscles, is transmitted via the nerves to the central nervous system. Of course, if a dip in the glucose concentration in the blood flowing to the brain does occur, it is directly detected by specialized nerve cells and a neuro-hormonal reaction is launched immediately.

Too much of a good thing

Humans have inherited their genes from their forebears, who had difficulties in acquiring food and had to survive long periods of hunger. This is why our mechanisms to counteract the excessive accumulation of fat are not very well developed. We are somewhat protected from obesity by post-meal themogenesis, mentioned above. Through the activity of the sympathetic nervous system, this process intensifies the idle cycles in the liver and muscles. After a diversified meal, the increased energy expenditure so caused can lead to the dissipation of some 10-15% of the energy contained in food. Nevertheless, a protracted period of energy surplus can erode this mechanism's efficiency as well.

Research carried out at our centre has shown that the thermogenic effect of ingested glucose (the standard laboratory food) is lower in adults with higher body weight. This is caused by their reduced sensitivity to insulin, which stimulates the synthesis of complex compounds from simple nutritional components, as well as by reduced post-meal activity on the part of the sympathetic nervous system. Significantly overweight individuals usually demonstrate lesser physical activity and lower fitness. This is a factor that could have a direct impact on their energy balance. However, research has shown that this is also an important factor that reduces the thermogenic effect of food. Lower post-meal thermogenesis in adults can, with age, become secondary to the consequences of lesser physical activity and increased body weight. Yet age still might have a direct impact, since slim women above 70 years in age who lead active lives have been shown to manifest an inhibition of glucose's heat-generating action.

Epidemiological data points unambiguously to a higher incidence of obesity and its complications in very highly developed countries. These complications lead to a higher risk of contracting arteriosclerosis and diabetes, and consequently to greater mortality and higher treatment costs. ■

Further reading

Durnin J.V.G., Passmore R. (1967). *Energy, Work and Leisure*. London, Heinemann Educa-tional Books Ltd.

Kozłowski S., Nazar K. (1999). *Introduction to Clinical Physiology*. [in Polish]. Third Edition, PZWL, Warsaw

Keller J.S. (1996). *Sketch of Human Bio-Energy*. [in Polish]. Wydawnictwo SGGW, Warsaw.