Robustness is a property that allows a system to maintain its functions despite external and internal perturbations [1]. Biological robustness is the robustness of biological systems. The opposite of robustness is fragility. Biological fragility refers to the loss of the original function of the system when faced with external and internal perturbations.

Biological robustness is a property that widely exists in biological systems. At the level of physiological system, the form of robustness is the homeostasis of the internal environment. One example is the glucose homeostasis in the human body [2]. For example, after strenuous exercise, glucose has been consumed in large quantities, and the blood sugar level of the body decreases. The hypothalamus activates islet A cells to secrete glucagon and the adrenal medulla to secrete epinephrine. The combined effect causes elevated blood glucose level. After eating, another area of the hypothalamus can rapidly activates islet B cells to secrete insulin. Insulin can promote the synthesis of glycogen, and promote the conversion of glucose into non-sugar substances, thus reducing blood glucose level.

Examples of biological fragility also widely exist in biological systems. For example, the rainforest is a very fragile ecosystem. This is because the soil of the tropical rain forest is very poor [3]. Once the rainforest vegetation is destroyed, the nutrients are strongly leached and quickly lost, the surface plants are difficult to recover, and the whole ecosystem will collapse. Cytokine storm is another example of biological fragility. In the inflammatory response, immune cells at the site of infection secrete cytokines. Under normal conditions, this process is regulated by the human body. However, the release of cytokines may go out of control, resulting in rapid increases in cytokine concentrations. Cytokine storm is an important cause of acute respiratory distress syndrome (ARDS) and multiple organ failure [4].

Biological robustness is an integral part of survival because it allows the system to evolve stably and adapt to the changing environment. If DNA replication does not have a good error prevention and correction mechanism, the accumulated gene mutations will completely change the genome of an organism, and then the traits of an organism cannot be stably passed on to future generations. Fluctuations in the external environmental conditions are unavoidable. As a system that constantly exchanges material and energy with the outside world, biological systems must adapt to the fluctuations of the external environment within a certain range.

The consequence of high fragility is that systems are susceptible to loss of function in the face of interference. For biological systems, this may lead to individual death, the extinction of species and the collapse of the ecosystem. However, strictly speaking, fragility is unavoidable. According to the research by Carlson and Doyle [5], the improvement of system robustness on one aspect must be accompanied by the decline of robustness on another aspect. A system may be extremely vulnerable to rare perturbations if it is well robust to common perturbations. The cytokine storm is a

good example. It is speculated that cytokine storms are due to the over-reaction of the immune system to new, highly pathogenic pathogens [4]. The immune system, which is robust in the face of common pathogens, suddenly collapses when confronted with new pathogens and causes disaster to the host.

However, better adaptation to common disturbances obviously contributes to the survival of biological systems. Therefore, for biological systems, there are several strategies to improve biological robustness. First of all, negative feedback and positive feedback can be used to realize the dynamic balance of the system, such as the glucose homeostasis of the human body. Secondly, various means can be used to realize the same function and improve the stability of the system. For example, both the tricarboxylic acid (TCA) cycle and glycolysis can produce ATP. When the oxygen supply of cells is insufficient, the energy supply mode of cells will switch from TCA to glycolysis. In addition, the modular system also improves the biological robustness. The most typical example is the physiological structure of animals, which is composed of cells, tissues and organs. The death of a few cells does not affect the function of organs. (685 words)

Reference:

[1] Kitano H. Biological robustness. Nat Rev Genet. 2004 Nov;5(11):826-37. doi: 10.1038/nrg1471. PMID: 15520792.

[2] Khonsary SA. Guyton and Hall: Textbook of Medical Physiology. Surg Neurol Int. 2017 Nov 9;8:275. doi: 10.4103/sni.sni_327_17. PMCID: PMC5691553.

[3] Munawar, Ali. "Soil as A Fundamental Element of Silviculture for Sustainable Tropical Rain Forest Management." IOP Conference Series: Earth and Environmental Science. Vol. 394. No. 1. IOP Publishing, 2019.

[4] Channappanavar R, Perlman S. Pathogenic human coronavirus infections: causes and consequences of cytokine storm and immunopathology. Semin Immunopathol. 2017 Jul;39(5):529-539. doi: 10.1007/s00281-017-0629-x. Epub 2017 May 2. PMID: 28466096; PMCID: PMC7079893.

[5] Carlson JM, Doyle J. Complexity and robustness. Proc Natl Acad Sci U S A. 2002 Feb 19;99 Suppl 1(Suppl 1):2538-45. doi: 10.1073/pnas.012582499. PMID: 11875207; PMCID: PMC128573.