Biological Robustness and Fragility

Biological systems, including organisms, cells, and tissues, face numerous environmental and internal perturbations that challenge their normal functioning. Biological robustness and fragility are two essential aspects of the ability of biological systems to cope with such perturbations. In this essay, we define biological robustness and fragility, give examples of each, explain why biological robustness is an integral part of survival, discuss the consequences of fragility, and suggest ways to avoid it.

Robustness is a ubiquitous feature of biological systems. It ensures that specific functions of the system are maintained despite external and internal perturbations. System control, alternative (or fail-safe) mechanisms, modularity and decoupling are the underlying mechanisms that produce robustness [1]. Robustness is a measure of the resilience of a system to perturbations, including genetic, biochemical, and environmental ones. An example of biological robustness is the circadian clock, a cellular mechanism that regulates the timing of biological processes in organisms. The circadian clock is an essential adaptation that allows organisms to anticipate and adapt to daily changes in light and temperature[2]. The robustness of the circadian clock is critical for survival, as it ensures that organisms maintain their circadian rhythms even when exposed to fluctuating environmental conditions.

Biological Fragility is the opposite of robustness and refers to the susceptibility of a biological system to perturbations, changes, or stressors. An example of biological fragility is glucose homeostasis. The energy control system of our body is fragile against unusual environments such as high-energy content foods or low-energy utilization lifestyle, because the two regulatory feedback systems for glucose homeostasis are not directionally symmetric. Feedback provides tight control for glucose shortfall but loose control for overdosage. Multiple nested feedback loops are conserved across species to prevent low plasma glucose levels, but the feedback loop involving leptin and ghrelin does not counterbalance oversupply of glucose[3]. As a result, unstable supplement of food is a perturbation for which energy control systems are adapted and robust, but overnutrition is a historically unusual change and reflects the fragility of energy control mechanism.

Biological stability ensures that organisms can maintain stable state even when exposed to fluctuating environmental conditions, which is the premise of various biological activities. One example is human body temperature regulation. As the skin's cold receptors feel the decrease in ambient temperature, the stimulus is transmitted to the temperature regulation center through the nervous system, and then the efferent nerves

react to the temperature changes. Vascular contraction and reduced secretion of sweat glands reduce heat dissipation. Hormones are secreted to strengthen metabolism, increase heat production, and maintain a constant temperature. Biological stability ensures that organisms can maintain stable state even when exposed to fluctuating environmental conditions, which is the premise of various biological activities.

The consequences of biological fragility can be severe, including dysfunction, disease, or death. The fragility of chromosomes has been proven to be highly correlated with cancer: weaker chromosomes amplification, or non-random partial chromosome copy number gain, is often observed in cancer[4]. Meanwhile, Fragility can lead to the loss of resilience and adaptability, which can make organisms more vulnerable to perturbations. The body produces vitamin D from cholesterol direct sunlight on the skin when outdoors. In the process of human development from agrarian society to modern society, the decrease of exposure to the sun has led to rickets in children as well as osteoporosis in middle-aged and elderly people[5].

To counter the consequences of biological fragility, modern medicine has made some progress. Back to the previous discussion of vitamin D deficiency, the method of producing edible vitamin D on a large scale in industry has been invented, giving the public a low-cost and convenient way to supplement vitamin D, which greatly reducing the incidence of rickets and osteoporosis. Today's science and technology have provided new methods for the treatment and repair of the human body at the micro level, like gene editing, cell therapy, even artificial organs. All these technologies and treatment methods creates new possibilities for the remedy of biological fragility.

Reference

1. Kitano, H. (2004) Biological robustness. *Nat Rev Genet* 5, 826–837
2. Harmer, S.L. *et al.* (2001) Molecular bases of circadian rhythms. *Annu Rev Cell Dev Biol* 17, 215–253
3. Kitano, H. *et al.* (2004) Metabolic syndrome and robustness tradeoffs. *Diabetes* 53 Suppl 3, S6–S15
4. Richards, R.I. (2001) Fragile and unstable chromosomes in cancer: causes and consequences. *Trends in Genetics* 17, 339–345
5. Lips, P. and van Schoor, N.M. (2011) The effect of vitamin D on bone and osteoporosis. *Best Pract Res Clin Endocrinol Metab* 25, 585–591